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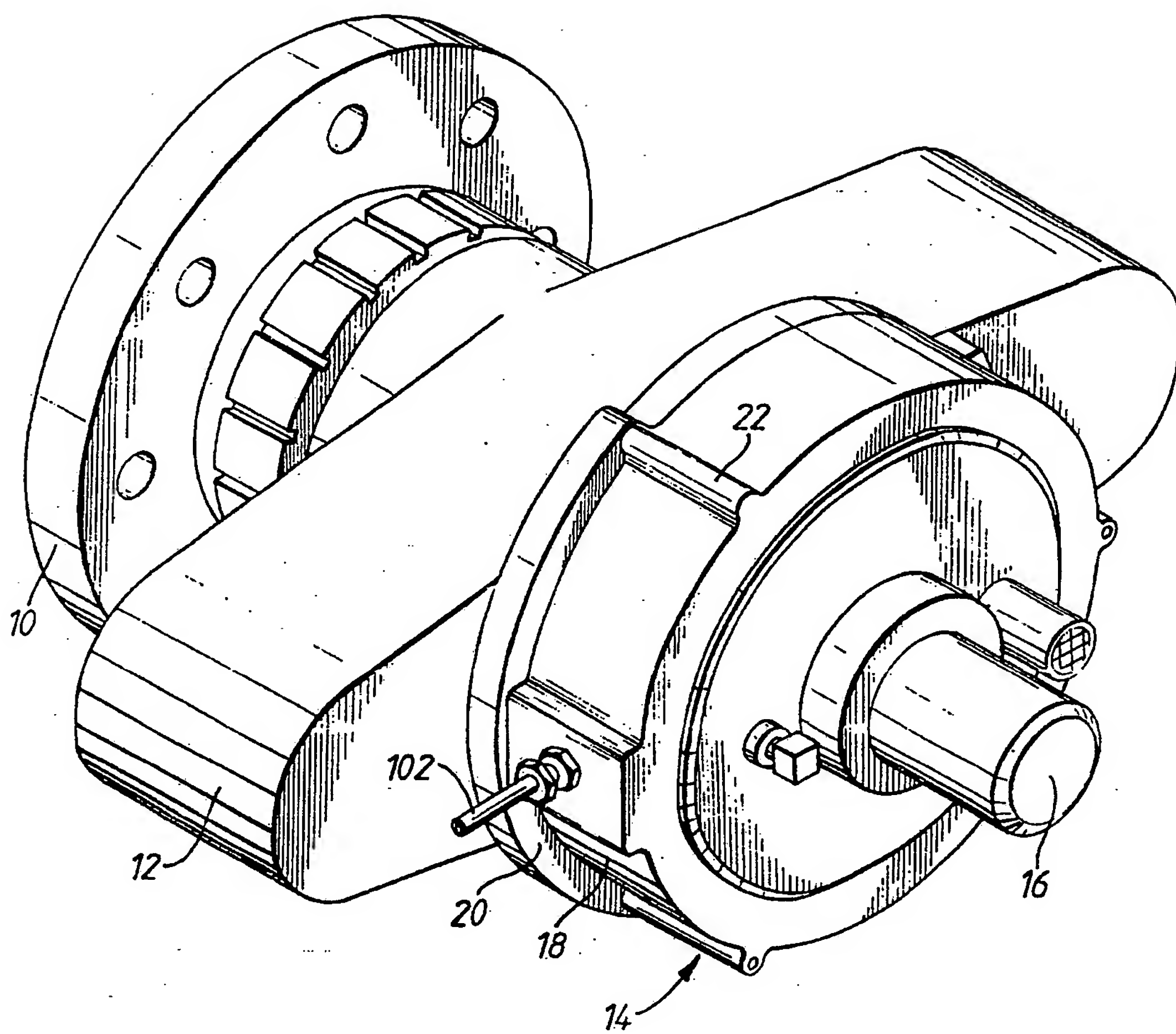
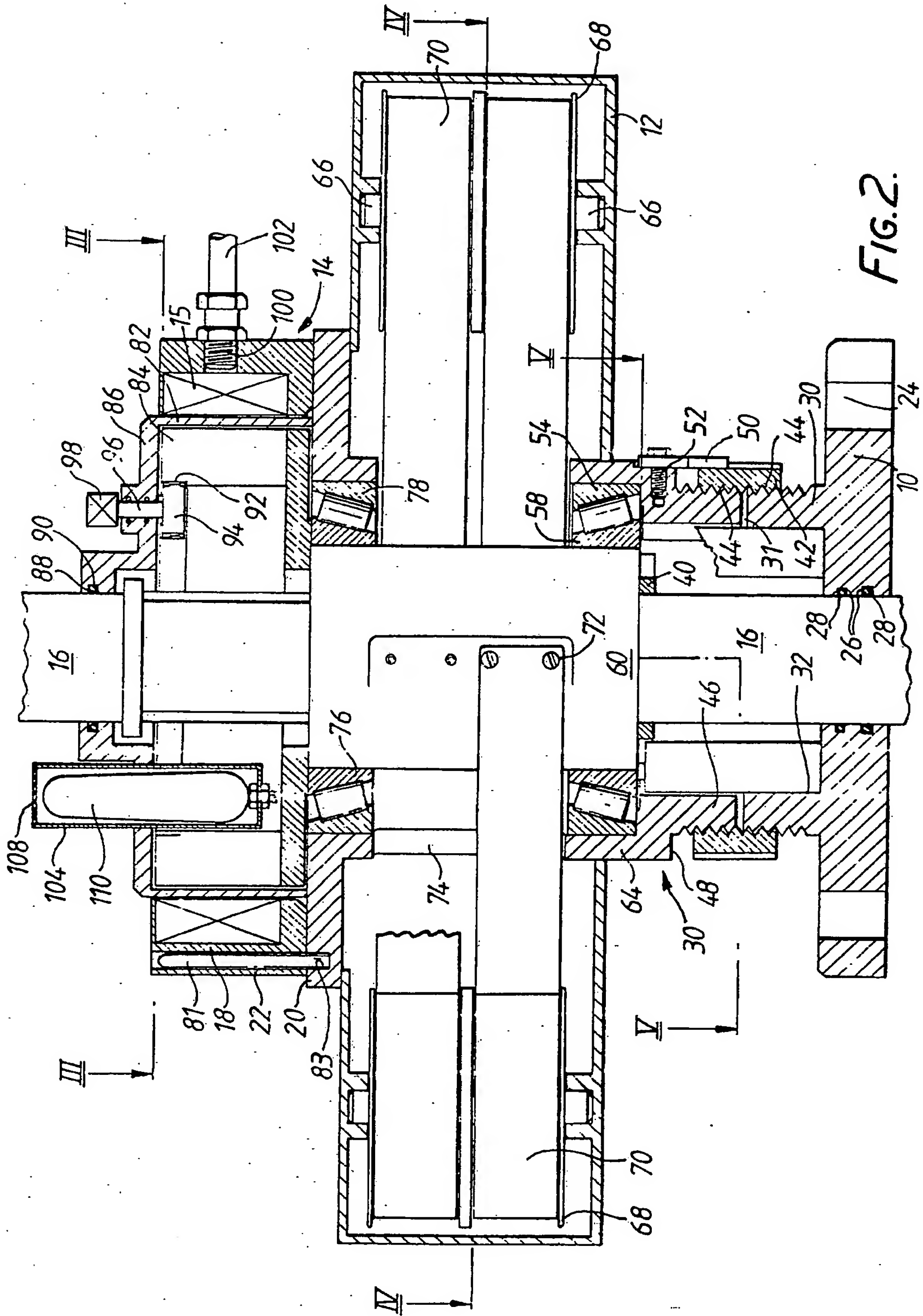


FIG. 1.



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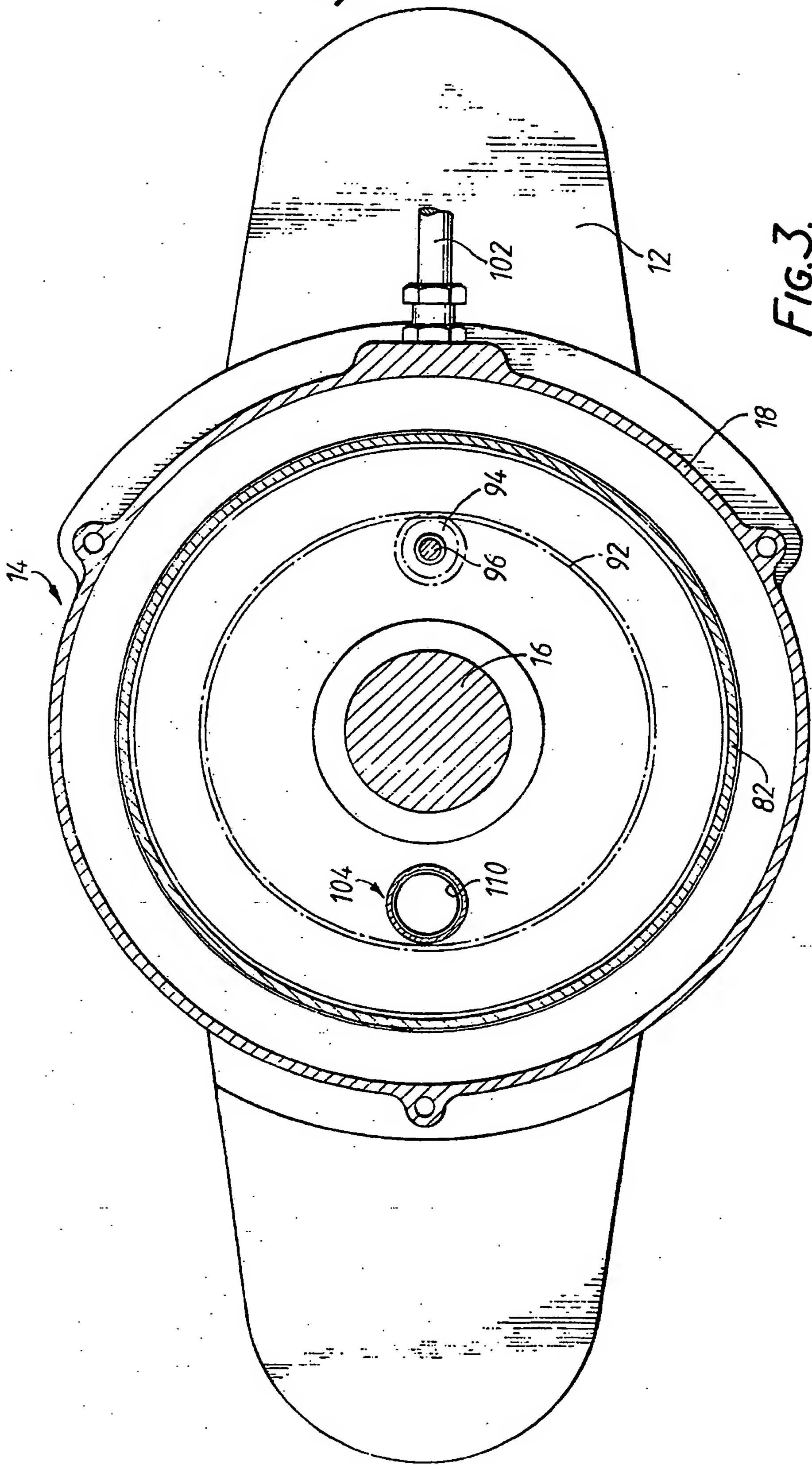


FIG. 3.

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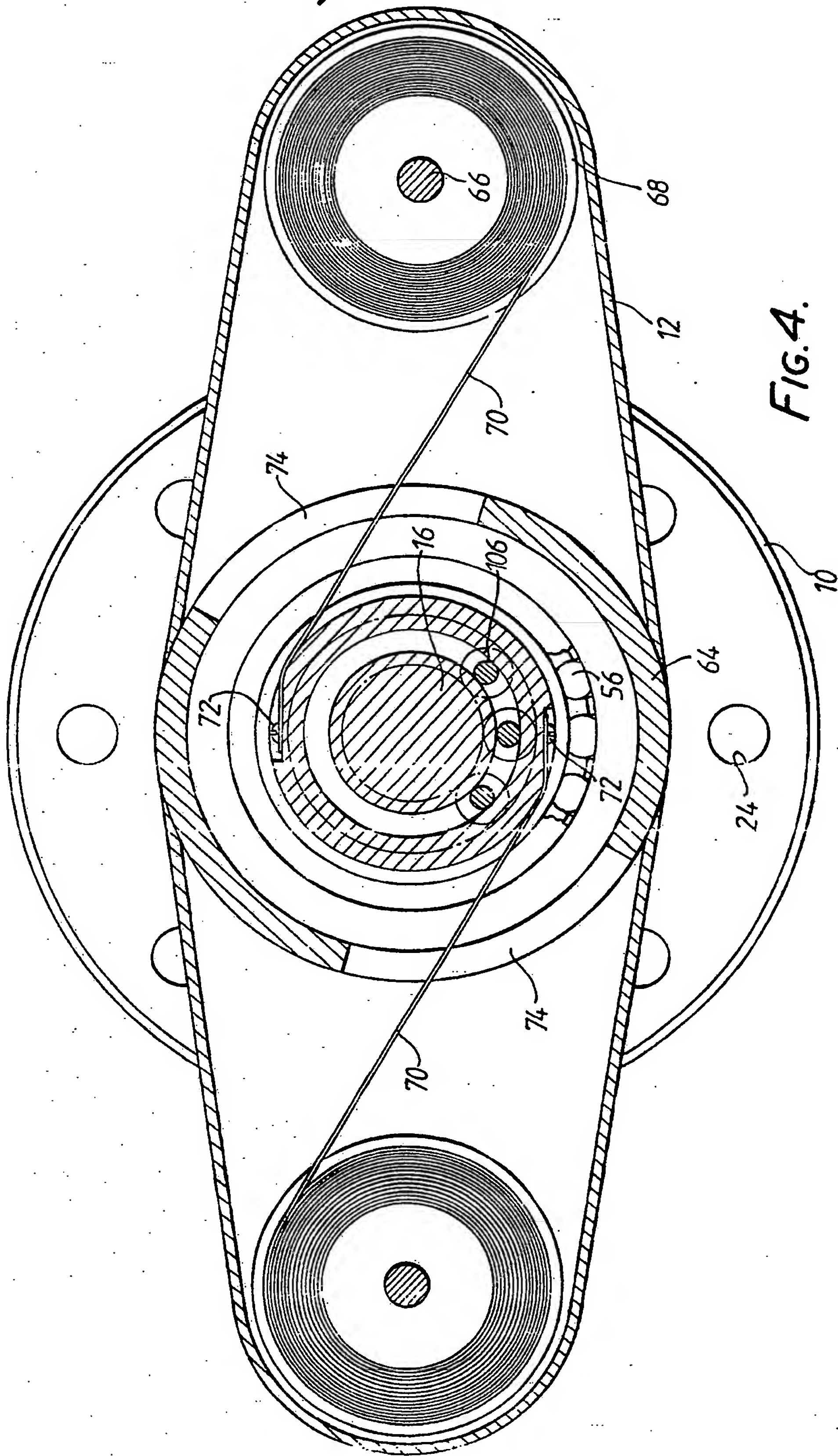


FIG. 4.

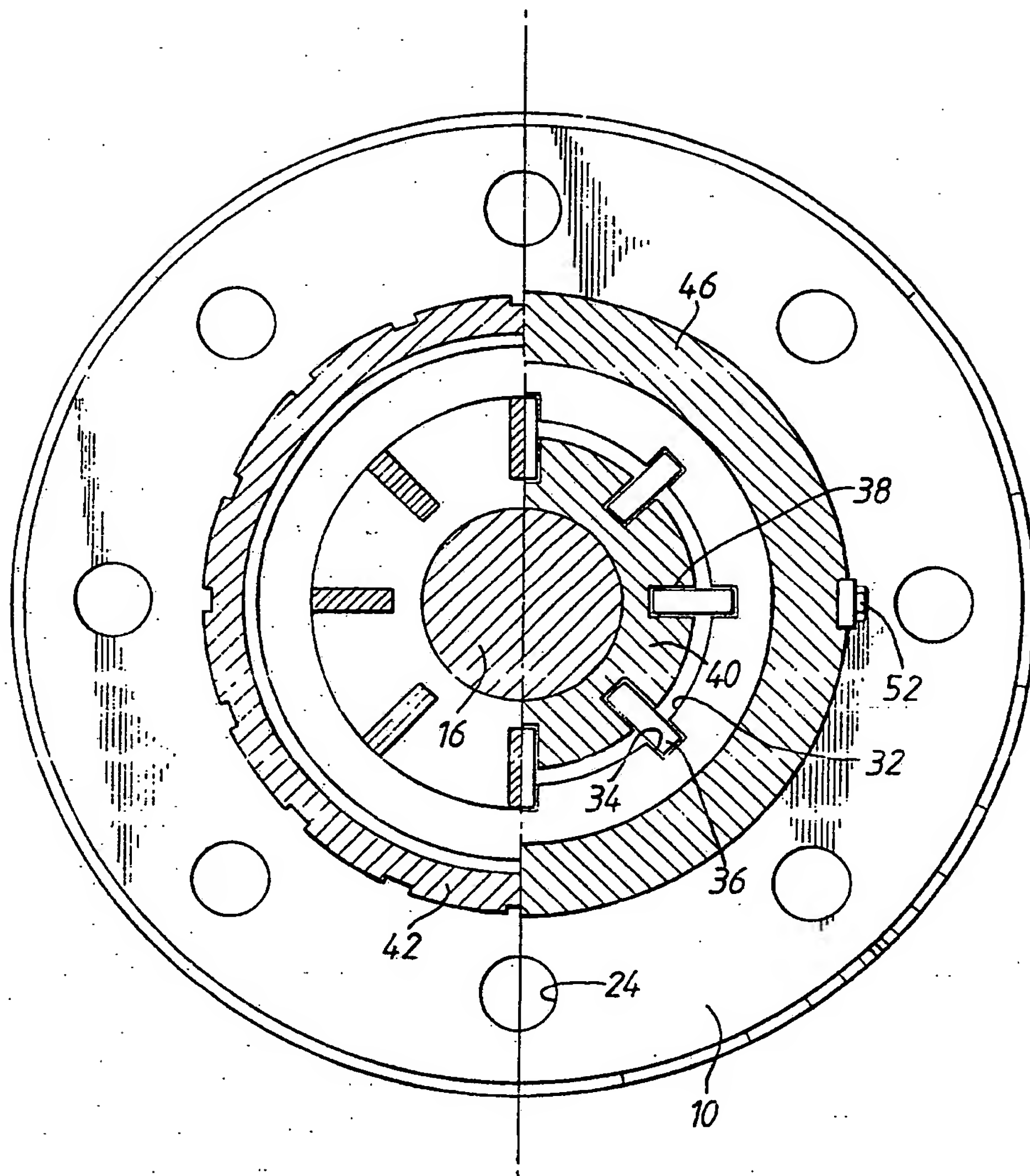


FIG. 5.

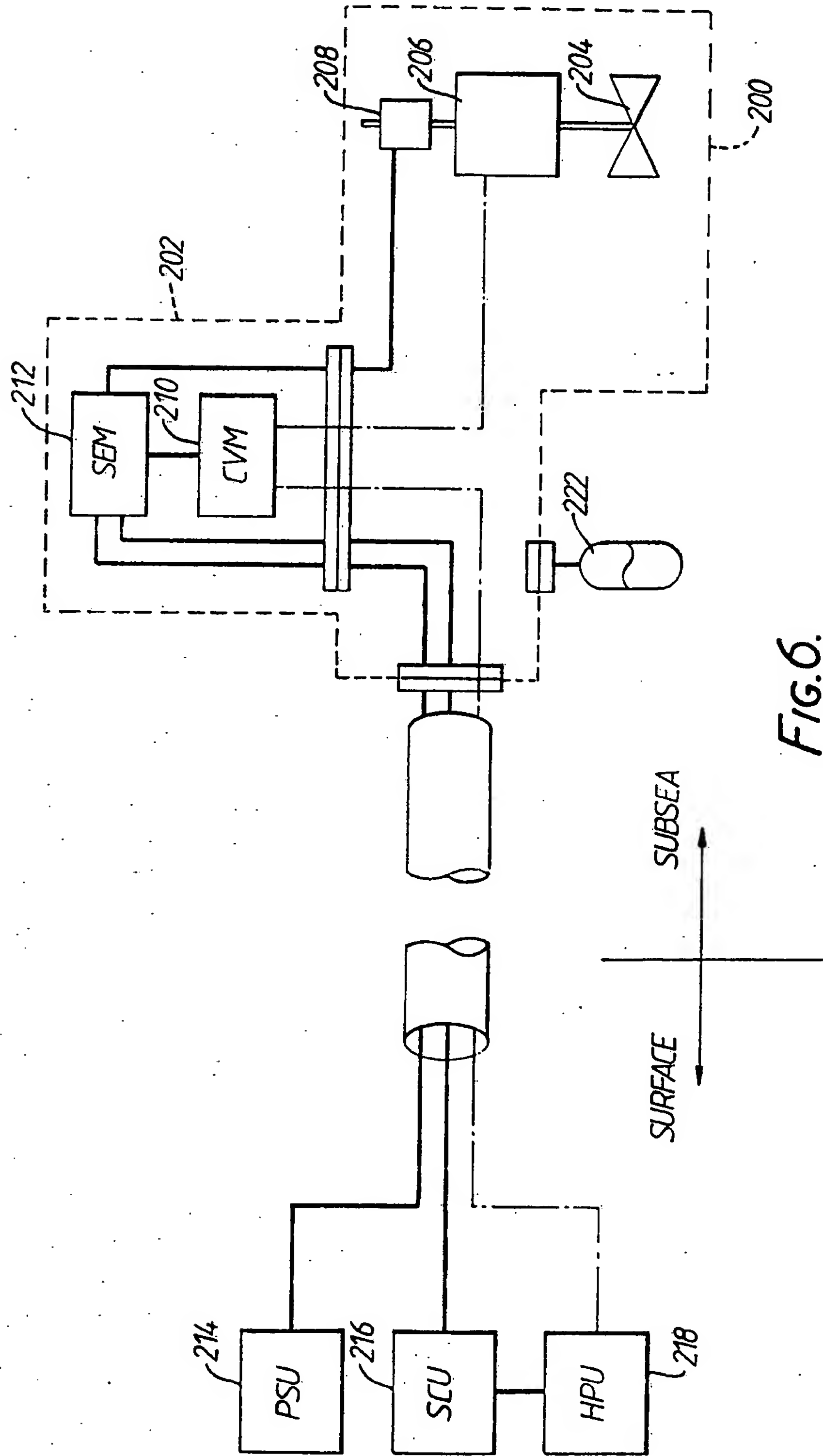


FIG. 6.



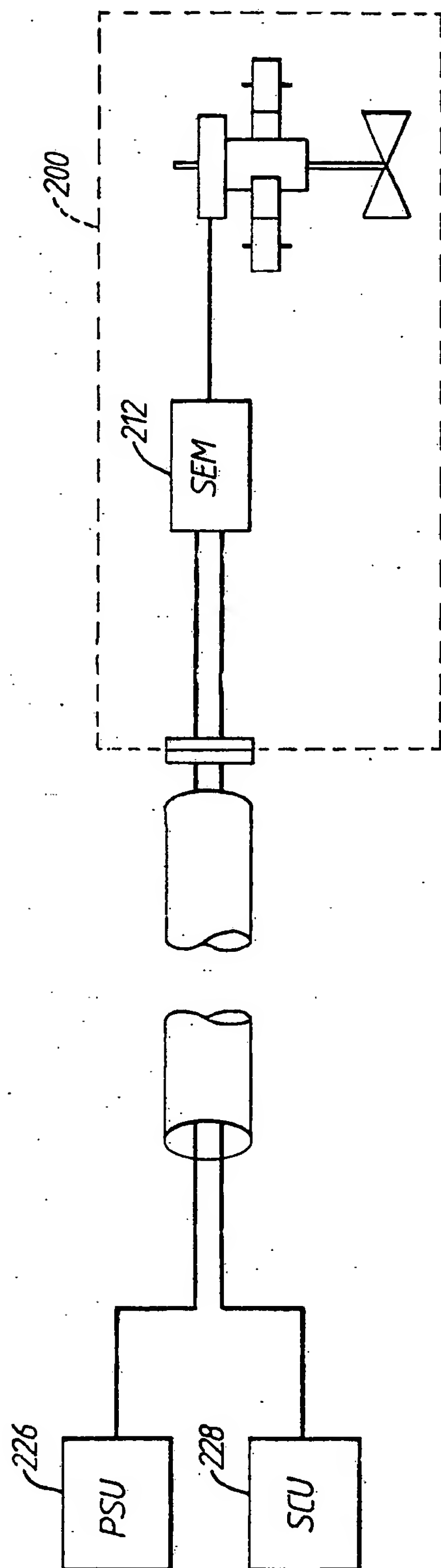


FIG. 7



### ELECTRICALLY-CONTROLLED VALVES

This invention relates to electrically-controlled valves for example those used in subsea situations in the hydrocarbons industry, i.e. gas and oil extraction. The invention relates more particularly to actuators for subsea valves of most types.

In broad terms electrically-controlled valves of many different kinds are available in industry, but under subsea conditions, it has been standard practice for a number of years to use electro-hydraulic actuation of various types of valve more especially gate valves. It is impossible to make a simple and direct transfer of a conventional electrically-controlled valve to subsea conditions owing to stringent safety requirements. Gate valves are basically very simple but the requirement for maximum safety has lead to increasing complexity in the electro-hydraulic actuators over the years which, in turn, has made the actuating systems for the movable valve member of the valve assembly both cumbersome, expensive, and less reliable than is desirable since any maintenance subsea involves quite obviously a very high cost penalty.

Existing control or actuator systems for electro-hydraulic

valves have evolved over a number of years with the result that additional components have been added to solve particular problems which have arisen and the overall result is not particularly satisfactory since the systems were not designed ab initio. Substantial efforts have been made to improve the reliability of the electrical components and sometimes in order further to increase the long term viability the components are provided in duplicate or even in triplicate.

From the hydraulic aspect the ancillaries of the hydraulic cylinders of the actuators conventionally used are bulky and costly; additionally helical failsafe springs have to be added which increase the bulk still further and locally disposed accumulators used for powering the actuation of the hydraulic cylinder further add to the amount of space taken up.

Further problems arise from leakage of control fluid; the prevention of this by elastomer seals is undesirable since they are liable to stick and deteriorate over a period of years. Hard seating does not suffer from this disadvantage but in a shearing mode leakage is inevitable. Even if the leakage is not of an oil-based fluid it is still undesirable owing to the need to maintain pressures for making up the often expensive control fluid. Leakage can

under some circumstances, even lead to the escape of oil with consequent environmental damage.

The disadvantages discussed are by no means exhaustive but it is clear that a change from existing electro-hydraulic actuators for many types of valve is desirable.

Broadly according to the present invention there is provided an all-electric subsea valve control system.

According to the present invention there is further provided an electrically-operated valve actuator comprising an electric motor, low-friction screw means coupled to the motor whereby to convert rotary to linear motion, means for transmitting the linear motion to a valve to be actuated, energy store means operative to bias the transmission means in a failsafe direction of the associated valve and means serving to lock the transmission means when the associated valve is in the configuration to which it is positively driven so long as the transmission means remains effective, failure of the transmission means serving to disable the locking means thus permitting the energy store means to move the transmission and hence the associated valve to the failsafe configuration.

Still further according to the present invention there is

provided an electrically-operated valve actuator comprising a D.C. motor, screw roller means coupled to the motor whereby to convert the rotary motion of the motor to linear motion, transmission means including shaft means for transmitting said linear motion to a valve to be actuated, energy store spring means operative to bias the transmission means in a failsafe direction of the associated valve, and means serving to lock the transmission means when the associated valve is in the configuration to which it is positively driven so long as the transmission means remains effective, failure of the transmission means as a result of failure of the electric supply to the motor or other cause serving to disable the locking means thus permitting the energy store spring means to move the transmission means and hence the associated valve to the failsafe configuration.

A subsea control actuator system embodying the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a perspective view of the control actuator in accordance with the invention;

Figure 2 is a longitudinal section of the actuator of Figure 1;

Figure 3 is a section on the line III-III of Figure 2;

Figure 4 is a section on the line IV-IV of Figure 2;

Figure 5 is a section on the line V-V of Figure 2;

Figure 6 is a diagram illustrating a conventional electro-hydraulic system; and

Figure 7 is a diagram illustrating a complete system in accordance with the invention incorporating the actuator of Figures 1 to 5.

Referring now to the drawings, Figure 1 is an external isometric view of a control actuator for a failsafe closed gate valve (not shown) which includes a mounting flange 10, a housing 12 for a failsafe constant torque spring motor and a constant torque D.C. motor 14. The actuator can also be used with a failsafe open valve. The motor is preferably brushless. Such motors have permanent magnet rotors and stators which include drive coils 15. Commutation is electronic and makes use of Hall Effect sensors (not shown) to detect the position of the rotor by changes in the magnetic field. In order to provide ready indication of the condition of the valve at any given instant the valve

actuating shaft 16 or other linear motion transmission means protrudes as illustrated in Figure 1 beyond the motor housing 14. The shaft 16 can alternatively be considered as the valve stem and the mounting flange can alternatively be considered as the valve bonnet which serves to seal the valve body against line pressure.

Preferably the stator 18 of the electric motor 14 is readily detachable and is prevented from rotating relative to a flange 20 immediately adjacent the failsafe spring motor housing 12 by dowels which pass through axially-extending ribs 22 of the motor stator housing. The stator is retained on the dowels by clip or other means and it will be apparent that the stator can be removed without disturbing the remainder of the motor and without disturbing the substantially hermetic sealing of the main casing. The overall compactness of the design is well illustrated by Figure 1. In the embodiment illustrated the dimension along the axis of the valve actuating shaft 16 is only approximately 600 mm; at the greatest width the failsafe spring motor housing 12 is only 730 mm across. This compares very favourably with comparable sizes of electro-hydraulic actuators where the overall axial length can be as much as three metres. It will be seen from Figures 2 and 4 that the spring motor housing is symmetrical about the transmission shaft axis.

Turning now to Figure 2, the flange 10 by which the control actuator is secured to the gate valve itself (not shown) is illustrated at the lower end of the Figure and apertures 24 through which securing bolts (not shown) are passed are plainly shown. At its internal diameter the flange has two annular grooves 26 each of which receives an O-ring seal 28 or other high pressure seal which contacts the gate valve actuating shaft 16. The seals are required to withstand high pressures in the range 700 to 1000 kg/cm<sup>2</sup>.

The flange 10 itself is integral with a cylindrical member 30 which, internally, defines in part a cylindrical chamber 32 which is, however, slotted at 34 (Fig. 5) to receive a plurality (eight as illustrated) of rectangular members or keys 36 which are also received in longitudinally-extending slots 38 of a bush or other hollow cylindrical member 40 which is secured to the main actuator shaft 16. The cylindrical member 30 is spaced by a gap 31 from a lower cylindrical casing part 46.

Outwardly of the bush 40 receiving the keys 36 there is an internally threaded turnbuckle collar 42 which engages with oppositely-handed screw threads 44. Rotation of the collar 42 by engagement of a tool with grooves on the outer periphery enables the gap 31 to be adjusted so that the



associated movable valve member will be accurately located at each end position, i.e. fully closed or fully open. The collar 42 can also be termed a drift adjustment collar since it serves to line up or "drift" the valve member precisely with the valve bore.

Upwardly, as viewed in Figure 2, beyond the collar 42 the casing is formed with a shoulder 48 and as illustrated immediately above the shoulder at the right hand side of the Figure a dependent finger member 50 is secured by a bolt 52 engaged into a tapped blind bore with part of the finger engaging in one of the grooves of the collar 42.

The keys 36 provide a rigid connection between the flange 10 and the main casing across the gap irrespective of the size of the latter. The uppermost end surface of the bush 40 also provides a stop to limit linear motion of the shaft 16.

Above the shoulder 48 the internal cylindrical chamber 32 is enlarged to receive the outer race 54 of a taper-roller bearing 56, the inner race 58 of which is a tight fit on a lower end portion of a nut 60 of a recirculating roller screw. Such recirculating roller screws are conventional items available, for example under the Registered Trade Mark TRANSOL which is marketed in the United Kingdom by Unimatic Engineering Ltd. This roller screw will be further

described with reference to Fig. 4. It is desirable that the screw means should be of low friction type such as an acme screw thread.

The failsafe spring housing 12 is mounted on an enlarged part 64 of the casing and by an upper flange 80 of the main casing. It has a shape as best illustrated in Figures 1, 2 and 4. This failsafe spring motor housing carries the shafts 66 of two pairs of coil-spring receiving members 68, two such receiving members being provided in each opposed half of the housing 12. The springs 70 are best illustrated in Figures 2 and 4 and as illustrated the shaft or stem is fully extended and the springs are unwound. In order to provide a sufficient torque the two springs are arranged in tandem one above the other and each is attached at a free end portion by set screws 72 to the nut 60 of the roller screw. The parts of the springs unwound from the members 68 pass through the main casing part 64 by way of openings 74.

Upwardly of the failsafe spring motors, an upper end portion of the roller screw nut 60 is further supported by a taper-roller bearing the inner race 76 of which is a tight fit on the nut 60, and the outer race 78 is a tight fit within a part of the main casing which generally has the form of the flange 20 extending radially outwardly from the upper end of

the casing part 64.

An auxiliary, separate, part 82 of the casing, of much thinner section extends from the upper face of this flange 20 and serves to enclose the permanent magnet rotor 84 of the electric motor 14. Within strength limitations the auxiliary casing is made as thin as possible and is made of non-magnetic material. This auxiliary part of the main casing also has a portion 86 extending radially inwardly and receives the upper part of the gate valve actuating shaft 16. To prevent leakage an O-ring seal 88 or other seal is provided in an annular groove 90 immediately adjacent the shaft.

The rotor 84 is formed by an annular magnet assembly and the inside of this annulus has a toothed ring 92 meshing with a pinion 94 mounted on a short spindle 96 passing through the auxiliary casing part 86. These parts form together a mechanical override. The outer end of the short spindle 96 carries a square section member 98 enabling the pinion to be turned manually when it is desired to adjust the actuator manually or by a tool mounted on a remotely operated subsea vehicle. The stator 18 is supplied with power through a terminal 100 and an associated cable 102 using a steel casing and hydraulic connector (known in itself). The stator is mounted on the flange 20 by a plurality of

dowels 81 which engage in bores 83 and can readily be demounted when necessary. The dowels prevent rotation of the stator relative to the main casing.

Turning now to the sections of Figures 3, 4 and 5, Figure 3 shows the pinion 94 in plan view and diametrically opposite a pressure compensator 104 which extends into the auxiliary casing 82. Such compensators are known in themselves and serve to compensate for volume differences in the oil within the actuator dependent upon the pressure at the operational depth. It is open to sea water through a grid 108 and includes a rubber bladder 110 which expands and contracts dependent upon the pressure.

Figure 4 shows details of one opposed pair of springs 70 and also the roller screw arrangement 60 which ensures that the torque required to operate the actuator is kept to a minimum. Roller screws of this type are known per se and will not be described in detail except to refer to the roller members themselves 106 which are grooved with the same pitch as the outer periphery of the actuator shaft and the inner periphery of the nut 60. Only three of these roller members are shown but in practice they will be evenly distributed around the whole of the space between the shaft 16 and the nut 60.

Figure 5 illustrates the manner of location of the keys 36 in the slots of the bush 40, the interior of the cylindrical member 30 and the interior slots of the casing part 64.

When assembled with a gate or other valve assembly the flange 10 is secured by bolts and an initial adjustment or drift action is carried out by applying a tool to the turnbuckle member 42 so that when fully closed there is no gap between the valve member and the seating of the valve body. Once the correct adjustment is achieved the locking tab or finger 50 is engaged in the nearest external groove in the turnbuckle member 42. It will be appreciated that the keys 36 accommodate an adequate range of adjustments and have sufficient strength to maintain integrity of the actuator casing. In order to actuate the valve the motor is energised from a local control pod or module (Fig. 7) which is itself normally controlled from a remote station. The time taken for closure (or opening) will be about 30 seconds but clearly this can be varied to meet particular requirements. On the assumption that the valve is of the "failsafe closed" type positive actuation to open the valve is required and once the open condition has been achieved the motor is maintained in a stalled condition by the electronic controls of the control pod. The voltage applied to the stator may, however, be reduced so that the torque is

just sufficient to overcome the opposed torque of the spring motor.

So long as the electrical supply continues and no mechanical transmission failure occurs, the valve will remain open until such a time as the motor is de-energised when the spring motor will effect the closing operation. If desired, however, the rating of the spring motor may be such that the closing operation requires assistance from the motor driven in the reverse sense.

The failsafe mechanism needs to work against two different forces in the associated "Christmas tree". One is the static friction in the gate of the valve (or other movable valve member) which depends upon the lubricity of the fluid in the line in which the valve is incorporated and upon the tendency of this line fluid to form solids such as wax or hydrates. The other force arises if the line pressure is lower than the hydrostatic pressure in the surrounding sea or other body of water. The pressure difference acts on the area of the valve stem and normally tends to open the valve. However, the line pressure is normally higher than the sea water pressure so that the differential tends to close the valve and hence to assist the failsafe mechanism.

It follows that the failsafe mechanism must be capable of

accommodating these force differentials and the almost constant torque provided by a spring motor makes such a motor particularly suitable.

If and when it is desired to adjust the actuator manually or by the remotely operated vehicle the pinion 94 is rotated by the square member 98 until the required motion has been completed.

In the event of failure of the electricity supply or a mechanical transmission failure in the actuator, the spring motor automatically closes the valve by use of the energy stored in the springs.

The extension of the shaft 16 beyond the main casing provides a visual and tactile indication of valve location. An electronics sensor could also be provided which senses the position of the rotor of the motor and hence the valve location.

Advantages of the present invention over conventional electro-hydraulic control or actuator systems are made clear from Figure 6, which shows a typical prior art system and from Figure 7 which shows in outline a system in accordance with the present invention.



In the prior art system a "Christmas tree" shown in broken lines and referenced 200 is directly connected with a control pod 202 (broken lines), the Christmas tree including at least one valve 204, a hydraulic actuator 206 and a valve position indicator 208.

The hydraulic actuator 206 is connected by a hydraulic line to a control valve module 210 within the control pod and this is itself connected to a subsea electronics module 212, the latter also being connected by an electrical circuit to the valve position indicator 208. Lines from the subsea electronics module and the control valve module pass through an umbilical cable to an electrical power supply unit 214, surface control unit 216, and a hydraulic power unit 218. The surface control unit and the hydraulic power unit are interconnected by the line 220. Subsea the line from the control valve module 210 through the umbilical is connected to a hydraulic accumulator 222.

Referring now to Figure 7 the Christmas tree 200 indicated in broken lines incorporates at least one valve 204 and at least one actuator 201 in accordance with the invention, the actuator being controlled only by a subsea electronics module 224 and this is connected to the surface by an umbilical connector to an electrical power supply unit 226 and a surface control unit 228. The module or pod 224 serves

for switching and power distribution and will be all "solid state". High power switching will be by way of thyrystors or power transistors. It follows that it can be built with inherent reliability and therefore need not be retrievable. The surface control means serves to lock the actuator shaft in its operated condition by maintaining power supply to the motor so that the latter is maintained stalled. In the event of power or mechanical transmission failure, the spring motor overrides to return the valve to its failsafe condition. It will be very readily appreciated that the overall system of Figure 7 is appreciably less complex than the overall system of Figure 6 and the advantages can be summarised as follows:

1. All controls required to convert electrical signals to hydraulic power are omitted together with all hydraulic connectors;
2. There is a substantial reduction in the bulk of the system as a whole as no accumulators are required and electronic power circuits are smaller than the hydraulic solenoid valves of conventional actuator systems. The actuators themselves are also less bulky;
3. It is possible to use large numbers of solid state components with consequent increased reliability;

4. By the use of an electronic control system the stroke rate of the valve can readily be controlled and may even be varied over the length of the stroke;
5. The valve can be driven closed to augment the failsafe spring motor action;
6. Use of electronics enable remote reading of the valve position; and
7. The umbilical is simpler since no hydraulic lines are required.

It is to be expected that a system in accordance with the present invention will be less costly than a conventional electro-hydraulic system, but the precise saving depends to a very large extent on the quality of the components used. This applies particularly to all cabling and connectors which require high quality, long life insulation. Furthermore, thorough sealing of all components is essential.

Figure 7 discloses the present invention in its broadest aspect, namely an all-electric subsea valve control system, all hydraulic aspects of the control having been eliminated.

It is to be noted that such a control system can also be used with ball valves and check or throttle valves, both types being conventionally used subsea. If necessary electronic feed-back of the instantaneous position of the movable valve member can be used to ensure effective control.

The term "subsea" is intended herein to cover not only locations beneath the sea surface but also locations below any other body of water.

Although the locking<sup>1</sup> means is preferably provided by the surface control unit and subsea electronic module so that the motor is stalled, it would be possible, alternatively to use a solenoid to act as the locking means. However, this involves an addition subsea component with a slightly higher reliability aspect to be considered.

CLAIMS

1. An all-electric subsea valve control system.
2. An electrically-operated valve actuator comprising an electric motor, low-friction screw means coupled to the motor whereby to convert rotary to linear motion, means for transmitting the linear motion to a valve to be actuated, energy store means operative to bias the transmission means in a failsafe direction of the associated valve and means serving to lock the transmission means when the associated valve is in the configuration to which it is positively driven so long as the transmission means remains effective, failure of the transmission means serving to disable the locking means thus permitting the energy store means to move the transmission and hence the associated valve to the failsafe configuration.
3. An electrically-operated valve actuator comprising a D.C. motor, screw roller means coupled to the motor whereby to convert rotary motion of the motor to linear motion, transmission means including shaft means for transmitting said linear motion to a valve to be actuated, energy store spring means operative to bias the transmission means in a failsafe direction of the associated valve, and means

serving to lock the transmission means when the associated valve is in the configuration to which it is positively driven so long as the transmission means remains effective, failure of the transmission means as a result of failure of the electric supply to the motor or other cause serving to disable the locking means thus permitting the energy store spring means to move the transmission means and hence the associated valve to the failsafe configuration.

4. An actuator according to claim 2 or claim 3, wherein the motor is a D.C. brushless motor.

5. An actuator according to claim 4 wherein the stator of the motor is detachable from externally of the actuator without affecting the substantially hermetic sealing of the actuator.

6. An actuator according to claims 2, 3 or 4, comprising mechanical override in the transmission means.

7. An actuator according to claim 6 wherein the mechanical override means includes a gear tooth annulus formed in or mounted to the inner periphery of the rotor of the motor which annulus meshes with a pinion mounted on a shaft-extending through the casing of the actuator and having means whereby the shaft and pinion can be turned from

externally of the casing.

8. An actuator according to any one of the preceding claims wherein the energy store means comprise constant torque spring motors connected to a nut member of the low-friction screw means.

9. An actuator according to any one of claims 2 to 7 wherein the low friction screw means or screw roller means comprise a nut connected to the energy store means, grooved rollers and an inner screw threaded member forming part of the transmission means, the rollers meshing both with the nut and with the inner screw threaded member.

10. An actuator according to any of claims 2 to 9 comprising drift adjustment means.

11. An actuator according to claim 10 wherein the drift adjustment means comprises a turnbuckle arrangement operative between a flanged member adapted to be secured to the associated valve and a main part of the actuator casing, means being provided to lock the turnbuckle arrangement in a selected position such that the associated valve is accurately located in its end positions after drive has been effected.



12. An actuator according to any one of claim 2 to 11, wherein the transmission means extends throughout the length of the actuator, the motor being mounted immediately adjacent the low-friction screw means and the energy store means being located radially outwardly of the transmission means and symmetrically in relation thereto.

13. A subsea valve control system comprising an electrically-operated valve actuator according to any one of claims 2 to 12, a subsea electronics module adjacent the actuator, an electrical power supply unit above surface, a surface control unit, an electrical connection between the actuator and the module and electrical connections between the module and electrical connections between the module and the power supply unit and between the module and the surface control unit.

14. A subsea valve control system comprising an electrically-operated valve actuator a subsea electronics module adjacent the actuator, an electrical power supply unit above surface, a surface control unit, an electrical connection between the actuator and the module and electrical connections between the module and the power supply unit and between the module and the surface control unit.

15. An electrically-operated valve actuator substantially as hereinbefore described with reference to Figures 1 to 5 of the accompanying drawings.

16. A valve assembly comprising an actuator according to any one of claims 2 to 12 or claim 15.

17. A subsea valve control system incorporating a valve actuator substantially as hereinbefore described with reference to Figures 1 to 5 and 7 of the accompanying drawings.

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